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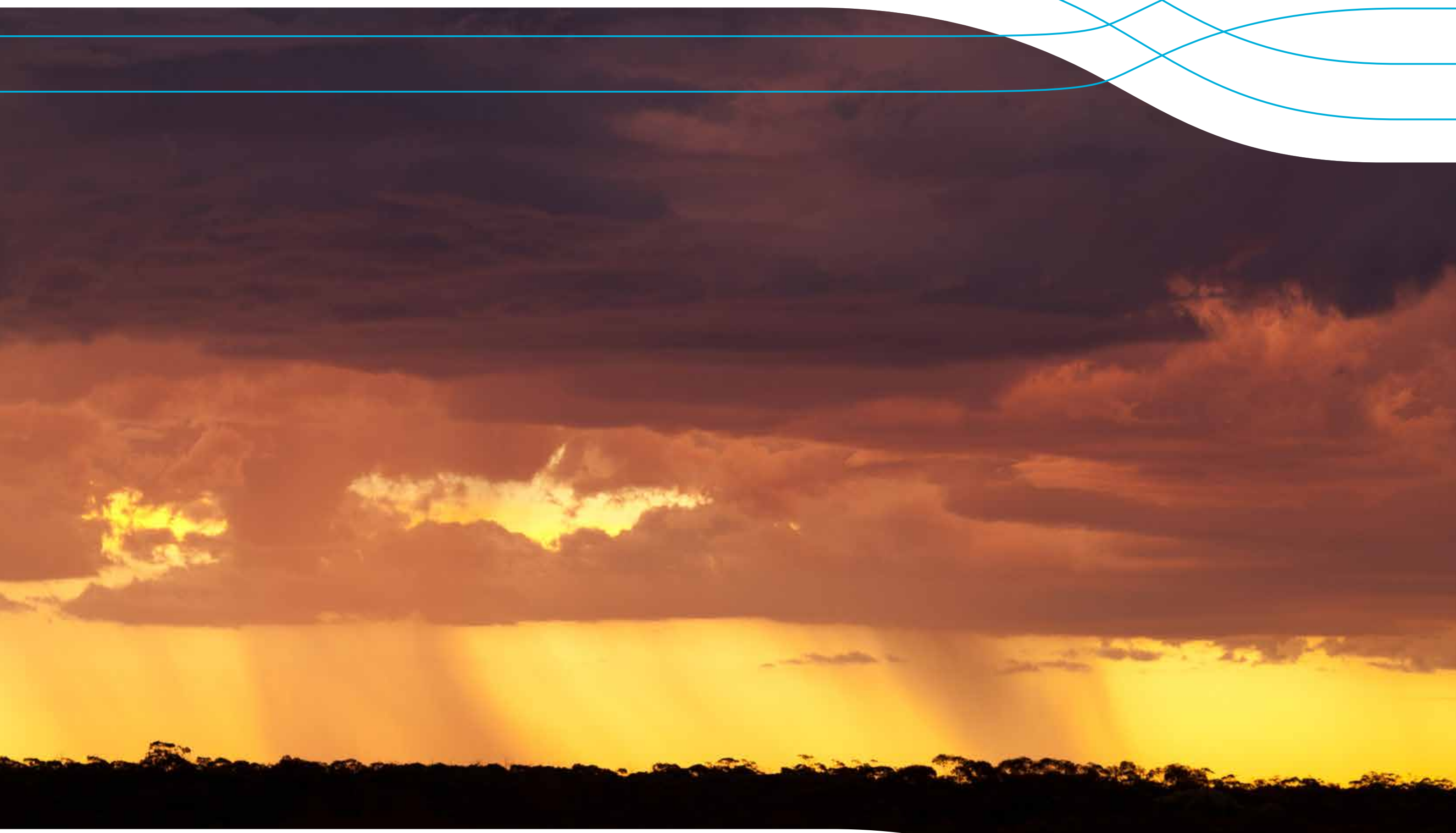
Pilbara Water Resource Assessment: Past, present and future hydroclimate

An overview report to the Government of Western Australia and industry partners from the CSIRO Pilbara Water Resource Assessment



GOVERNMENT OF WESTERN AUSTRALIA

Department of Water
Department of Regional Development

PILBARA DEVELOPMENT COMMISSION | PILBARA CITIES

ROYALTIES FOR REGIONS

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The Pilbara Water Resource Assessment

CSIRO has completed, for the Government of Western Australia and industry partners, an overview of the current and future climate and water resources of the Pilbara to aid water planning and management, and place local studies into a wider context.

The Assessment covers an area of 288,479 km², which is about 11% of the state of Western Australia. This is one of the world's most important resource regions because of high-grade deposits of iron ore and offshore gas reserves.

The Assessment examined surface water and groundwater resources and their environmental significance in detail for four regions within the Assessment area: Ashburton Robe, Upper Fortescue, Lower Fortescue Hedland and De Grey Canning (Figure 1). There is also a technical report, *Hydroclimate of the Pilbara: past, present and future*. These reports can be downloaded from www.csiro.au/Pilbara-water-assessment.

Figure 1 Reporting regions in the Pilbara Water Resource Assessment area

KEY POINTS

- Only 2% to 13% (6 to 50 mm) of mean annual rainfall becomes **runoff** in the Pilbara. Between 8 and 30 mm of rain is required to initiate runoff. While the number of events that produce runoff may decrease under a dry future climate scenario, the rainfall threshold is not expected to substantially change. Soils dry rapidly between most events because potential evaporation greatly exceeds rainfall across the area.
- **Rainfall** in the Pilbara results from both tropical and more temperate meteorological processes, making projections of future changes difficult because they vary in their response to raised greenhouse gases. The 2030 and 2050 climates almost certainly will be hotter. While global climate models project both wetter and drier conditions, the drier projections are more extreme.
- **Streamflow** exceeds **recharge** volumes by 5 to 6 times. This difference is the result of very large flows during cyclonic events and tropical depressions exceeding the amount of water that can infiltrate during these events.
- **Groundwater** is currently the main water resource in the Pilbara. Most aquifers are recharged by water infiltrating through streambeds during large rainfall events. Alluvial coastal aquifers, an important local drinking water supply, appear capable of withstanding a hotter and drier climate because the proposed reduction in recharge is much less than the reduction in runoff and number of flow days.
- Groundwater resources in the Pilbara have important environmental value in supporting multiple terrestrial ecosystems. **Groundwater-dependent terrestrial vegetation** and river pools, marking groundwater discharge zones, occupy less than 0.5% of the Assessment area.
- Within the Assessment, **provinces** were defined so that discrete, local information on climate, surface water hydrology, groundwater hydrology and groundwater-dependent ecosystems could be integrated, enabling trends and patterns to be identified, analysed and discussed across the entire area.

CITATION

CSIRO (2015) Pilbara Water Resource Assessment: past, present and future hydroclimate. An overview report to the Government of Western Australia and industry partners from the CSIRO Pilbara Water Resource Assessment. CSIRO Land and Water, Australia.

This report is an overview of the following report: McFarlane DJ (ed.) (2015) Pilbara Water Resource Assessment: past, present and future hydroclimate. A report to the Government of Western Australia and industry partners from the CSIRO Pilbara Water Resource Assessment. CSIRO Land and Water, Australia.

Cover: Storms over the Pilbara © Janelle Lugge/Shutterstock

Key findings for hydroclimate

- The Pilbara is a semi-arid region that is significantly surface water limited, given that annual potential evaporation can exceed annual rainfall by more than an order of magnitude.
- There is an apparent enhancement in annual rainfall over the Hamersley Range, with corresponding lower potential evaporation, relative to the surrounding plains.
- The Assessment area mean rainfall for the baseline historical climate period from October 1960 (shown as water year 1961) with September 2012 (water year 2012) was 334 mm/year, compared with the long-term (1911 to 2012) mean of 299 mm/year (Figure 2). About 60% of annual rainfall falls between January and March.
- An exceptionally wet 7-year period from 1995 to 2001 had a mean annual rainfall of 500 mm/year (Figure 2). Western Australia experienced more tropical cyclones than average during this period.
- The majority of climate change projections indicate that tropical cyclones may become less frequent overall but that the strongest tropical cyclones may increase in intensity and size, and travel further south.
- There are linear trends of increasing annual rainfall, extreme rainfall, number of rainfall days and mean rain day intensity for the 1961 to 2012 period in the east of the Assessment area, with opposing decreasing trends in the western third.
- Winter rainfall has decreased in the western Pilbara because cold fronts have progressively reached less far north since the mid-20th century.
- The cause for the increase in summer rainfall in recent decades may be climate change, natural variability, aerosols emanating from South-East Asia, or some combination of these.
- On balance, projections indicate that the Pilbara may become slightly drier by 2030 and 2050, although wetter projections cannot be discounted. There is not sufficient confidence in the projections to allow quantification of the probabilities of the wet or dry scenarios occurring in the future.
- The median projected warming relative to the historical climate (mid-point in 1986) is 1.5 to 1.6 °C for 2030 and 2.1 to 2.9 °C for 2050, for a medium greenhouse gas emission scenario (representative concentration pathway (RCP) 4.5), and for a high greenhouse gas emission scenario (RCP8.5), respectively.
- The corresponding median projected annual rainfall changes are –0.1% to –1.8% for 2030 and –0.1% to –2.5% for 2050, for RCP4.5 and RCP8.5, respectively.
- The selected future wet scenarios have projected annual rainfall increases ranging from 3.2% (2030, RCP4.5) to 7.8% (2050, RCP8.5).
- The selected future dry scenarios have projected annual rainfall decreases ranging from –4.2% (2030, RCP4.5) to –17% (2050, RCP8.5).
- The corresponding projected areal potential evaporation changes range from annual increases of 3% to 4% for 2030 and 4% to 7% for 2050.
- Annual rainfall deficits increase for all future climate scenarios because of the projected increases in areal potential evaporation.

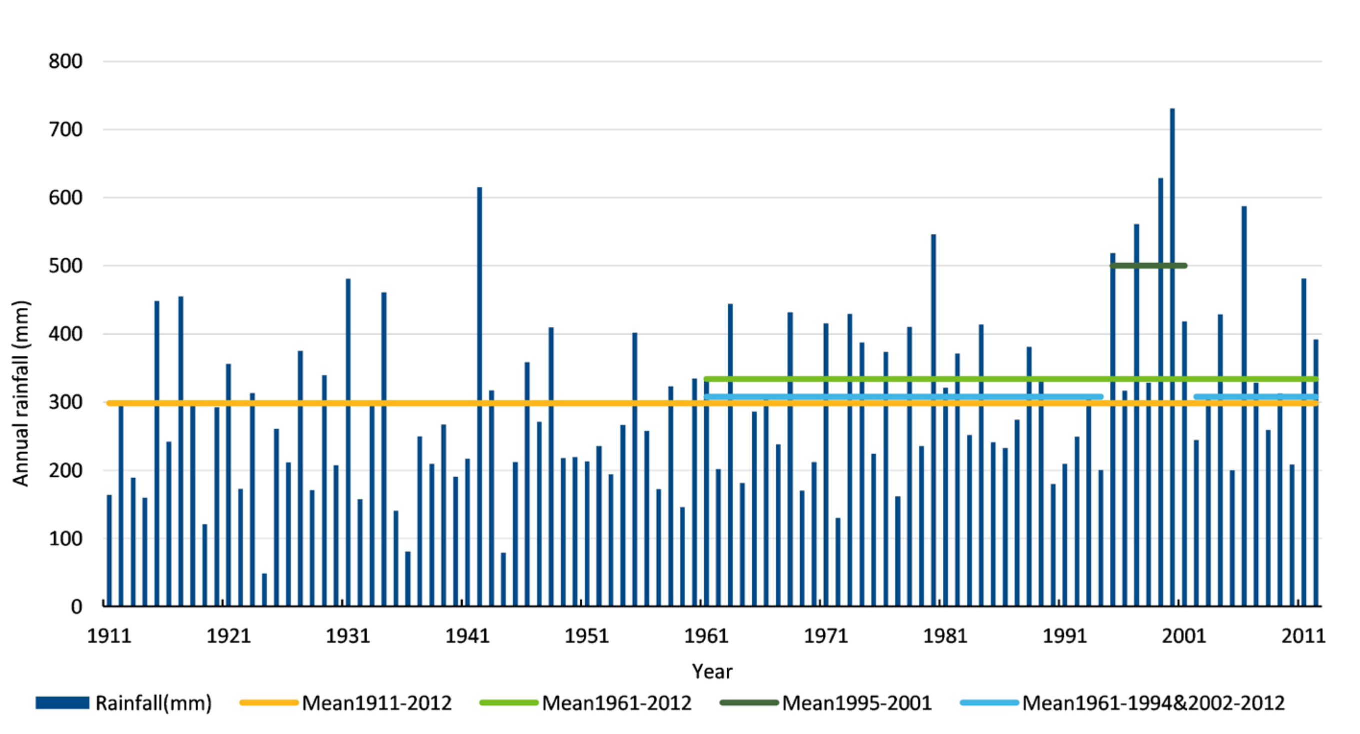

Figure 2 Average annual (October to September water year) total rainfall for the Assessment area for 1911 to 2012, showing means for certain periods

Past, current and future climate

This summary assesses changes to climate that have a direct and immediate effect on hydrology, as the magnitude and timing of rainfall influence both runoff and recharge rates. Increased evaporative losses, predominantly as a result of increased temperatures, also result in greater aridity.

Analyses of climate processes and data were undertaken to summarise and interpret the climate drivers influencing observed climate variability and trends.

The Assessment area is influenced by the Australian monsoon to the north-east and the adjacent warm northern seas that generate tropical cyclones and tropical depressions. The marked seasonality and large year-to-year variability of these and associated processes, together with the strong seasonality in the temperature contrast between land and ocean, result in highly seasonal and variable rainfall. This ranges from local-scale intermittent, intense rainfall to large-scale persistent rainfall.

The Pilbara is a semi-arid region that is significantly water limited, given that annual potential evaporation can exceed annual rainfall by an order of magnitude. The Assessment area's 1911 to 2012 mean annual rainfall is 299 mm (Figure 2). There is large year-to-year variability, with annual rainfall ranging from 48 mm in 1924 to 731 mm in 2000.

The wettest months are January to March, producing 60% of annual rainfall. February is the wettest month, with an average of 71 mm, or 24% of the annual rainfall, and September is the driest, with an average of 2 mm, or 0.6% of the annual rainfall. There are also strong spatial gradients, with higher annual rainfall over the Hamersley Range (up to 500 mm) and 100 km inland of the north-east coast (Figure 3). This is indicative of a trough line, which is preferential to thunderstorms, with advection and convergence of moist sea breezes, together with uplift from orography (Hamersley Range) and heating (e.g. the Marble Bar region). The rainfall of the recent 1990–2012 period shows a large increase, relative to the long term, over the north-east Canning Basin, as well as an extended region of enhanced rainfall over the Hamersley Range (Figure 4). This shorter period contains the very wet 7-year period 1995 to 2001, and hence the increased magnitudes reflect the influence of these extreme years.

Mean annual potential evaporation across the Assessment area, calculated using Morton's wet areal formula, ranges from 1700 mm in the south-east to more than 2000 mm in the northern coastal parts (Figure 5). It most probably underestimates the inland potential as it does not account for advection due to dry and hot inland winds. Potential evaporation varies seasonally from an average of 7.3 mm/day in December and January to 2.8 mm/day in June and July. This results in a calculated mean annual rainfall deficit ranging between 1200 mm over the Hamersley Range and 1750 mm along the coastline and eastern inland parts of the Assessment area.

Potential evaporation estimated from Class A pan evaporation is much higher than that estimated by Morton's formula because it is measured from a small water body with a dry surrounding environment and accounts for wind-induced advection. Morton's wet areal formula is used for modelling because it can be readily estimated across the Assessment area using available climate data. Class A pan evaporation is more applicable for estimating evaporation from isolated water bodies such as dams and mine pit lakes.

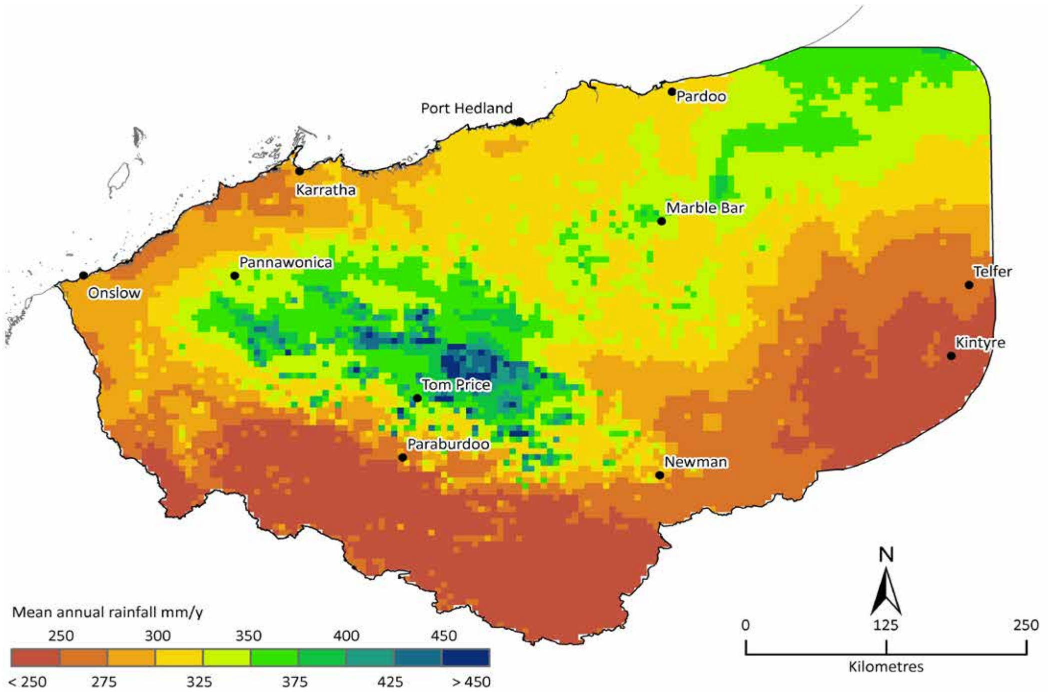

Figure 3 Mean annual rainfall (mm/year) for the period 1911 to 2012

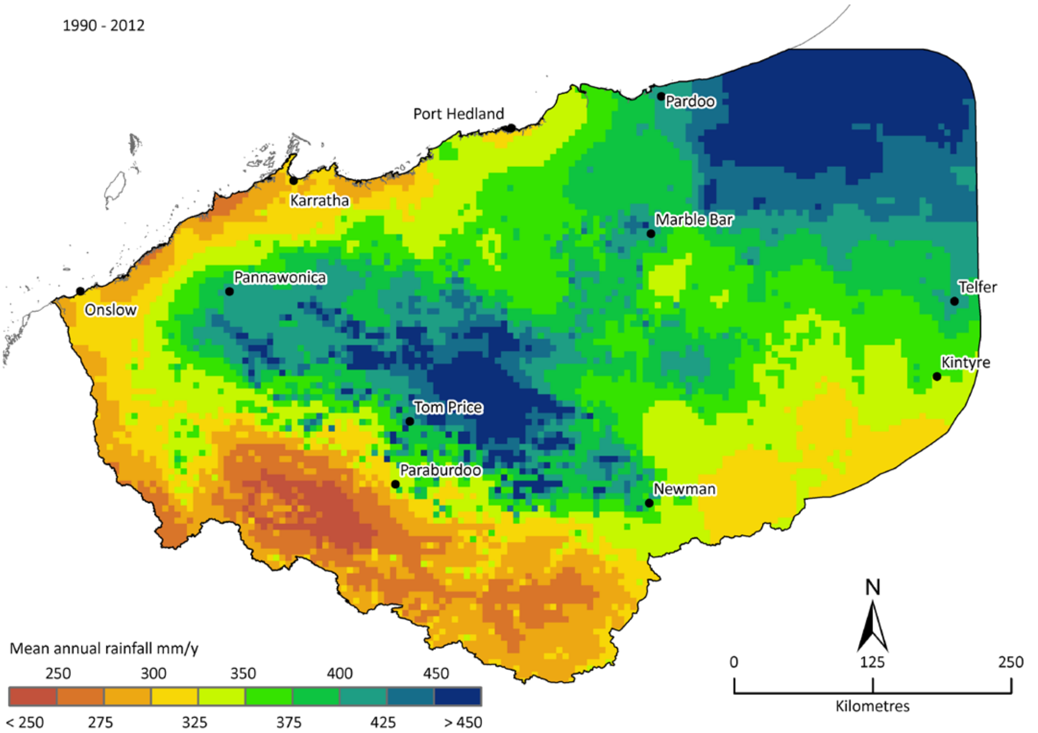

Figure 4 Mean annual rainfall (mm/year) for the period 1990 to 2012

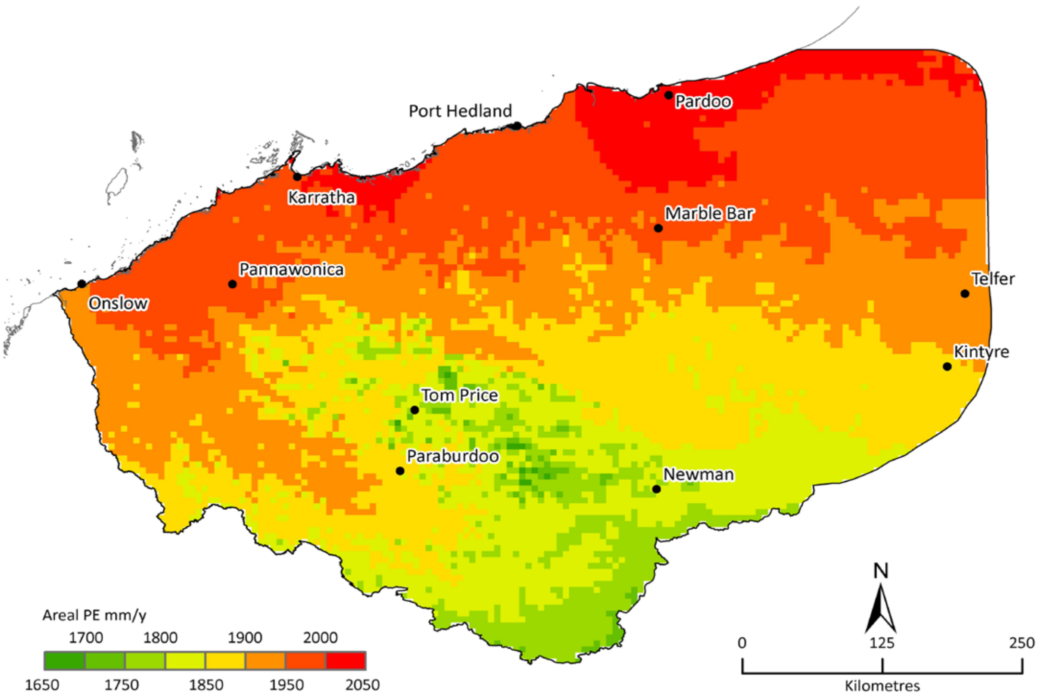

Figure 5 Mean annual potential evaporation (mm/year) calculated using Morton's areal wet environment method for the period 1911 to 2012

The magnitude and direction of long-term trends in rainfall varies across the Assessment area. Overall, annual rainfall trends have strengthened over more recent periods compared with the long-term trends, as highlighted by the spatial distribution of trends across different periods (Figure 6).

The 1961 to 2012 period was identified as having somewhat larger trends than most other periods, with rainfall increasing in the eastern parts and decreasing in the western parts of the Assessment area (Figure 7). The decrease in the west is partially attributed to a decrease in winter rainfall due to cold fronts being displaced to the south as high pressure systems in the mid-latitude ridge intensify. There is some indication that the trends in total rainfall are more related to trends in high-intensity rainfall (particularly 99th percentile daily rainfall) than to the number of rain days or the average rain day intensity (Figure 7).

Time trends at individual stations are shown as the cumulative difference from the mean for five high-quality stations (Figure 8). These highlight the progressive drying (falling trend) over the early part of the record, followed by consistent and ongoing wetting (rising trend) since the 1960s for most stations, with particularly rapid wetting since the 1990s for the inland east (Bonney Downs) and inland central (Mount Florance) stations. The wetting trends continue in the most recent years for three eastern and central stations (Bonney Downs, Roebourne and Mount Florance), whereas the two westerly stations (Mardie, on the coast, and Mount Augustus, to the south-west) show recent declines.

The significantly wetter period of 7 years from 1995 to 2001, with an average annual rainfall of 500 mm (Figure 2), experienced more frequent tropical cyclones than average. The largest increases in monthly rainfall in the 1961 to 2012 period occurred in February, March and December – months with the highest historical frequency of tropical cyclones.

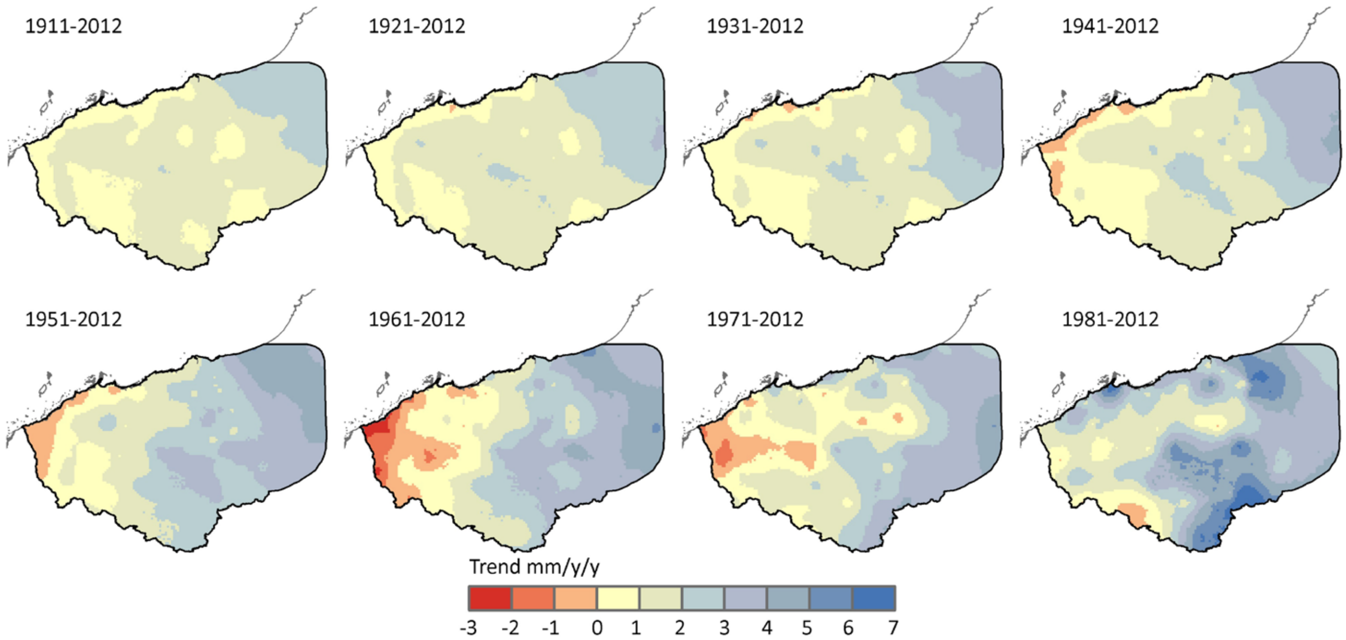

Figure 6 Trends in annual rainfall (mm/year/year) for periods ranging from the last 102 years (1911 to 2012) to the last 32 years (1981 to 2012)

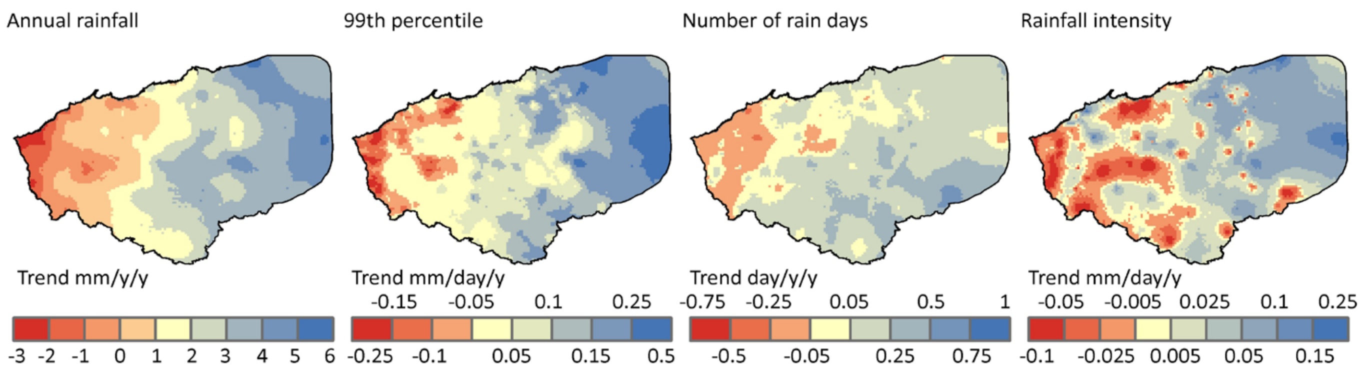

Figure 7 Trends for 1961 to 2012: (a) annual rainfall, (b) 99th percentile daily rainfall, (c) number of rain days >1 mm, and (d) rainfall intensity

Palaeoclimatological research indicates that the Pilbara has experienced past periods of intense aridity, and that the recent wetter decades may be unprecedented within the last several hundred years. Past analogues can not be directly related to current changes, however, as the rate of change caused by current climate change is much faster than that of past natural changes.

Because many climate processes interact to affect climate across the Assessment area, the spatial variability and trends are complex and not easily attributed to simple cause and effect. There is no scientific consensus as to the specific cause(s) of the increasing wet-season rainfall observed in recent decades over the north-west of Australia, including the eastern Pilbara. Possible causes of the observed circulation, wind and moisture flow changes include: (i) expansion of the tropical zone, (ii) increased atmospheric aerosol loads over the Asian region, and (iii) sea surface temperature changes, both remotely, from the tropical Atlantic or tropical western Pacific, and regionally, from the warming Indian Ocean.

Changes to the future frequency and intensity of tropical cyclones and monsoon depressions will be relevant to the continuation of observed trends. While one recent study concluded that the frequency of tropical cyclones could increase throughout the 21st century, many more studies concur with CSIRO findings of fewer but more intense tropical cyclones in the future. Thus, the weight of current understanding supports decreases in the frequency of tropical cyclones impacting the Assessment area as more likely than increases. Several studies also show that the intensity of tropical cyclones may increase in the future.

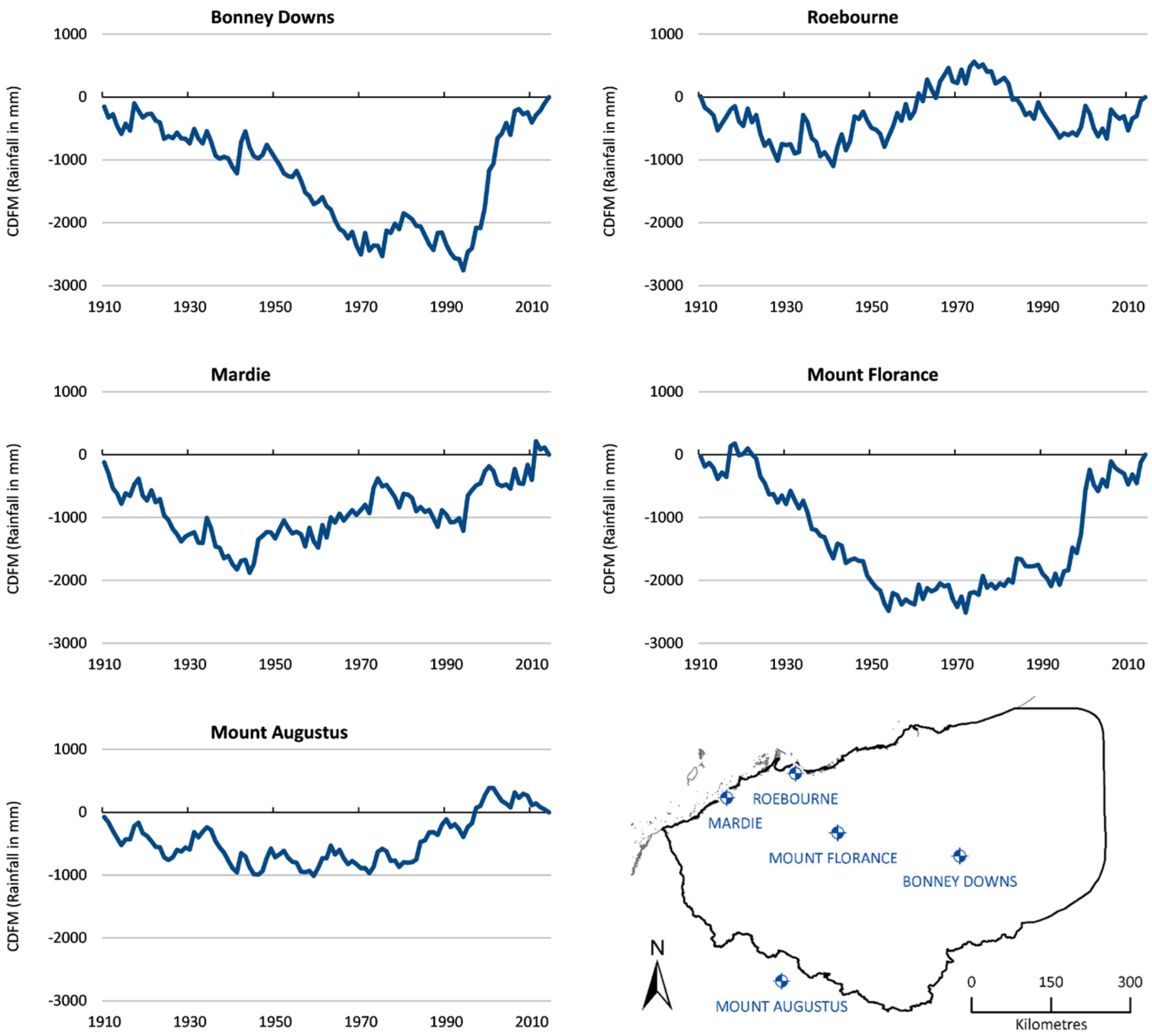

Figure 8 Cumulative difference from the mean time series for five stations with high-quality long-term records. Falling trends are 'dry' periods and rising trends are 'wet' periods. Locations of stations are shown in bottom right panel.

Global climate models (GCMs) are used for climate change projection. However, even if GCMs were able to adequately represent all large-scale processes and their interactions, the climatic changes affecting the Assessment area over the next several decades can not be predicted with certainty. This is because (i) it is not easy to predict the factors influencing the rate of global change in greenhouse gas emissions, such as the rates of economic and technological growth, and their resulting emissions profiles; and (ii) the regional response to global forcing is still highly variable across the latest GCMs. Given this uncertainty in future climate trends, a scenario approach using projections of plausible climate futures from many GCMs was used to account for the range of possible changes to climate baselines. The Assessment used the latest GCM scenarios from the Fifth Coupled Model Intercomparison Project (CMIP5), as used in the most recent Intergovernmental Panel on Climate Change Fifth Assessment Report, for medium (RCP4.5) and high (RCP8.5) changes to radiative forcing. The RCP numbers refer to the approximate radiative forcing levels by 2100 – that is, 4.5 W/m^2 and 8.5 W/m^2, respectively. RCP4.5 represents increased emissions of greenhouse gases until about 2040 and then reductions due to the implementation of mitigation, whereas RCP8.5 represents a future with little curbing of emissions and rapidly rising greenhouse gas concentrations.

Scenarios of daily rainfall and potential evaporation on 0.05 degree grid cells across the Assessment area were developed for climate inputs into hydrological models. The historical baseline (Scenario A) is the daily data rainfall and areal potential evaporation for the period 1961 to 2012. These series are modified according to a scaling approach to produce perturbed versions (Scenario C), representing 2030 and 2050 climates as projected by 18 CMIP5 GCMs.

The projections from the GCMs indicate that the largest rainfall changes result from projected decreases in December to February rainfall under the RCP8.5 scenario in 2050. Overall, the majority of GCMs project changes within 5% of the current climate mean for both 2030 and 2050. From the ensemble of Scenario C time series for 2030 and 2050, the RCP8.5 and RCP4.5 ensemble members that produced the 90th, 50th and 10th percentile rainfall changes for the Assessment area are identified as the Cwet, Cmid and Cdry scenarios, respectively.

The projected changes to Assessment area temperature range from 1.2 to 1.8 °C for 2030 and 1.8 to 2.9 °C for 2050 (Table 1). Although the median projected rainfall change (relative to the 1961 to 2012 baseline) is a relatively small 2% reduction by 2050, some scenarios project much larger changes, ranging from reductions of 17% to increases of 8% by 2050 (Table 2).

Median potential evaporation projections are for increases of 3% for 2030, rising to increases of 7% for 2050 (Table 3). Thus, on balance, the projections indicate that the Pilbara may become slightly drier by 2030 and 2050. A small rainfall reduction may have a larger proportional impact on the region's hydrology, given the known sensitivity of hydrology to small changes in rainfall, as well as the projected higher temperatures and potential evaporation.

While a small majority of models project drier and warmer conditions, several indicate that the Pilbara could become wetter and warmer. Even though wetter models are in the minority, they should not be discounted, as they are often better than the drier models at reproducing some of the large-scale climate processes influencing the Pilbara hydroclimate. Thus, as well as using the median projected scenarios, wet and dry scenarios were used to investigate the hydrological impacts of a range of projected changes for both 2030 and 2050.

Hamersley Range outcrop

Table 1 Assessment area mean annual temperature changes (relative to Scenario A) under Cwet, Cmid and Cdry future climate scenarios from 18 GCMs' RCP4.5 and RCP8.5 emissions scenario projections for 2030 and 2050

PERIOD	SCENARIO C	RCP4.5 EMISSIONS SCENARIO CHANGE (°C)	RCP8.5 EMISSIONS SCENARIO CHANGE (°C)
2030	C30wet	1.4	1.2
	C30mid	1.5	1.6
	C30dry	1.6	1.8
2050	C50wet	1.8	2.1
	C50mid	2.1	2.9
	C50dry	1.8	2.7

Table 2 Assessment area mean annual rainfall changes (relative to Scenario A) under Cwet, Cmid and Cdry future climate scenarios from 18 GCMs' RCP4.5 and RCP8.5 emissions scenario projections for 2030 and 2050

		RCP4.5 EMISSIONS SCENARIO		RCP8.5 EMISSIONS SCENARIO	
PERIOD	SCENARIO C	(%)	(MM)	(%)	(MM)
2030	C30wet	3.2	11	5.6	19
	C30mid	−0.1	0	−1.8	−6
	C30dry	−4.2	−14	−12.6	−42
2050	C50wet	4.5	15	7.8	26
	C50mid	−0.1	0	−2.5	−8
	C50dry	−5.9	−20	−17.4	−58

Table 3 Assessment area mean annual areal potential evaporation changes (relative to Scenario A) under Cwet, Cmid and Cdry future climate scenarios from 18 GCMs' RCP4.5 and RCP8.5 emissions scenario projections for 2030 and 2050

		RCP4.5 EMISSIONS SCENARIO		RCP8.5 EMISSIONS SCENARIO	
PERIOD	SCENARIO C	(%)	(MM)	(%)	(MM)
2030	C30wet	3.0	57	2.2	42
	C30mid	3.2	60	3.1	59
	C30dry	3.8	72	3.8	72
2050	C50wet	4.0	76	4.1	77
	C50mid	4.7	89	6.6	125
	C50dry	4.4	83	6.5	123

Banded iron formation at Fortescue Gorge

Basis of the Assessment

Our ability to quantify the hydroclimate of the Assessment area is limited by uncertainties that are difficult to quantify. There are variations in the observing network, both spatially and temporally, that limit our confidence in the spatial patterns and trends presented. The GCM climate change projections are inherently uncertain, given the wide range of regional response to the prescribed global forcings, as well as uncertainty as to which GCMs perform better. Thus, the scenarios are not accurate predictions of the future, but plausible possible futures.

The most uncertain aspect of the Pilbara's future climate is rainfall. Recent decades have shown a wetting trend extending from the north and east. But the cause of this trend is uncertain. GCMs in general do not project this trend accurately with more supporting a drier future than those projecting a wet future. However, all models project a hotter future climate. The choice of which scenario, or group of scenarios, to consider may depend on the purpose of the assessment and the risk of getting it wrong.

Pool in Coongan River, Marble Bar

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